The Observation by Means of a String Electrometer of Fluctuations in the Ionisation Produced by γ-Rays.*

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A γ-ray is a projected entity, according to the theories of J. J. Thomson,† of Bragg,‡ and of J. Stark,§ and the effect of it will be localised in space in the sense that the effect of a bullet is. Any one of these theories requires the ionisation produced by γ-radiation in a gas at any instant to fluctuate both in space and time. In this respect the effect of γ-rays would be similar to that of α-particles; as is well known, the spinthariscope exhibits for the latter rays both fluctuations in time and discontinuity in space. Similarly, the effects predictable for β-rays have been observed, but, when the experiments recorded below were begun, no such fluctuation had been observed for γ-rays. In 1908 one of us described how they might be sought for experimentally: "At the same distance from a source of γ-rays, two identical and adjacent ionisation chambers would be placed to catch the γ-rays. With one chamber at $+v$ volts and the other at $-v$, the electrode of one receives positive ions, the other negative; connecting the electrodes, the electroscope would receive the small excess of ions of one sign. If the γ-radiation is a spherical wave surface, then the ionisations in the chambers will have a constant ratio. This is true . . . . even when the energy varies continuously over the wave front; the excess current to the electroscope is then to a first approximation constant. If, on the other hand, the γ-rays are particles emitted in random directions as α-rays are, then the number entering each chamber in the given time will fluctuate. In the extreme case, during a short time a few γ-particles might enter one chamber, and none the other. In the more general case, when some large number of particles enter both chambers, the current to the electroscope will fluctuate."||

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* [The paper was forwarded from New Zealand on December 8, 1911, so that the more recent literature had not reached the authors.—Sec. R.S.]

† J. J. Thomson, 'Proc. Camb. Phil. Soc.,' 1907, vol. 14, Part IV, p. 423.

‡ W. H. Bragg, 'Phil. Mag.,' 1907, vol. 14, p. 429.

§ J. Stark, 'Phys. Zeit.,' 1910, vol. 11, p. 24.

|| Abstracted from the application, in 1908, for the Royal Society grant, which defrayed part of the expenses of this investigation.

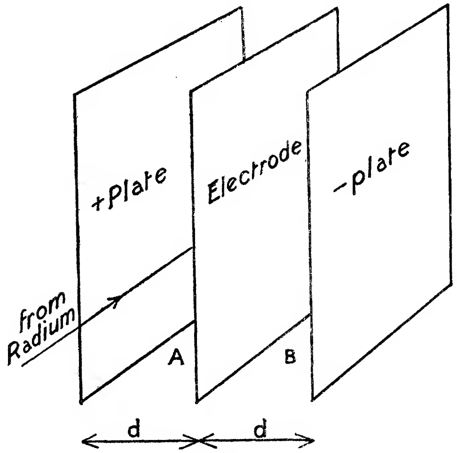

Fig. 1.

With the above arrangement, fluctuations have been observed in the ionisation produced by γ-rays. The two volumes of gas (see fig. 1) ionised were equal, and on opposite sides of one electrode, which collected the positive ions from one volume and the negative from the other; the radium, the source of the γ-rays, was equidistant from, and symmetrically placed with respect to, the two volumes. Yet the number of ions in the two volumes varied, sometimes one having an excess, sometimes the other. Spurious effects were eliminated with some difficulty; finally, however, the fluctuations ceased when the radium was removed. Thus the ionisation due to γ-rays is discontinuous in space; the discontinuity may be due to (1) the γ-rays being projected entities, or (2) a variation in the number of ions produced in a gas by the passage of a single γ-ray.*

Von Schweidler† in 1910 discussed in a theoretical paper the possibility of distinguishing between the continuous electro-magnetic pulse theory‡ and the projected entity (corpuscular) theories; he concluded that the counting of the elementary processes produced by γ-rays in a limited space constituted a crucial experiment. The experimental arrangements he proposed are indicated in fig. 2. The ionisation in C will fluctuate in intensity on either the pulse or corpuscular theory, for if the disturbance acting on C is a pulse it is discontinuous in time, if corpuscular both in time and space. Von Schweidler went on to consider how these elementary processes are to be detected and counted. As γ-rays do not give scintillations,[*] and Rutherford and Geiger's[†] method would probably fail, these two direct methods, which have been used for counting α-particles, are not available to count γ-rays. He suggested that an indirect method of counting γ-rays is afforded by his theory of the fluctuations which arise in the occurrence of any finite number of radioactive processes in accordance with the usual laws of chance.[‡] He thought, however, that the γ-rays may make too few ions for his theory to be experimentally realisable, for if the number of γ-rays, z, to be counted was sufficiently large to produce a discernible ionisation the fluctuation, E, which is proportional in absolute value to $\sqrt{z}$ (*i.e.* proportional to $1/\sqrt{z}$ of the whole ionisation), would be too small to measure. But in this relation we have, theoretically at any rate, as Von Schweidler pointed out, a distinction between the two theories of γ-rays, assuming that the number of ions made by a γ-ray is constant and not itself subject to fluctuations.[§] This distinction may be best made clear by an account of Dr. Edgar Meyer's experiments.[||]

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* There is a good deal of evidence that γ-rays as such do not ionise, but that the ions are produced by the β-rays resulting from the γ-rays (see Bragg, 'Phil. Mag.,' September, 1910, p. 385).

† Von Schweidler, 'Phys. Zeit.,' March, 1910, vol. 11, p. 225.

‡ Stokes put forward in the Wilde Lecture this theory to explain Röntgen rays ('Proc. Manchester Lit. and Phil. Soc.,' July, 1897, vol. 41).

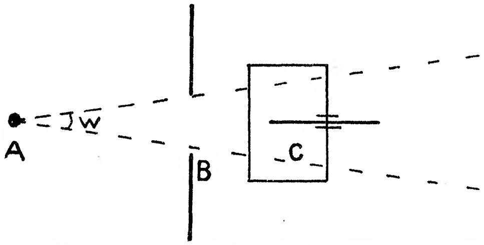

Fig. 2.—A, radium source of γ-rays ; B, screen with variable aperture ; C, ionisation can.

In the first of these experiments Meyer seeks to discriminate between the pulse and projected entity (corpuscular) theories of γ-rays by comparing the fluctuations in the ionisation in C (fig. 2) when using first a beam of γ-rays[¶] of solid angle ω and next of ω'. The fundamental distinction is that on the pulse theory the number of γ-rays entering C in a given time is on the average the same in the two experiments, while on the entity theory the number of γ-rays entering C is proportional to the solid angle.

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[*] Rubens, 'Phys. Zeit.,' 1909, vol. 10, p. 826.

[†] Rutherford and Geiger, 'Roy. Soc. Proc.,' August, 1908, A, vol. 81, p. 141.

[‡] E. von Schweidler, 'Int. Cong. de Rad.,' Liège, 1905 ; see abstract in 'Le Radium'; compare N. R. Campbell, 'Proc. Camb. Phil. Soc.,' February, 1909, vol. 15, p. 117, and 1910, pp. 310, 513.

[§] In a subsequent paper mentioned later von Schweidler investigated the theory of fluctuations for γ-rays without this assumption.

[||] E. Meyer, 'Berlin Berichte,' June, 1910, vol. 32, p. 647.

[¶] From 16·5 mgrm. of $RaBr_2$.

On the corpuscular theory

$$E_1/E_2 = ke\sqrt{z_1}/(ke\sqrt{z_2}) = \sqrt{(i_1/i_2)},$$

where E is the fluctuation in the ionisation, k the number of pairs of ions produced by each of the z γ-rays, e is the ionic charge, and i the saturation current. The suffixes refer to the screens used to limit the solid angle of rays. Thus, on the corpuscular theory, the ratio of the fluctuations in the two tests is equal to the square root of the ratio of the saturation currents, making the important assumption that the number of ions produced per γ-ray is constant. On the pulse theory, the number of ions produced by a pulse must depend on the portion of the whole disturbance that is allowed to act on the gas under observation. In this case we have

$$E_1/E_2 = K_1e\sqrt{z'}/(K_2e\sqrt{z'}) = K_1/K_2 = i_1/i_2,$$

where K is the number of ions produced by the effective portion of each of the z' γ-pulses.

Using three ratios of screen aperture, a large number of experiments gave—

E_1/E_2.	$\sqrt{(i_1/i_2)}$.	i_1/i_2.
1·01	1·19	1·41
1·44	1·38	1·88
1·28	1·23	1·50

These results support the corpuscular theory, for E_1/E_2 is clearly somewhat nearer in value to $\sqrt{(i_1/i_2)}$ than to i_1/i_2; but since the detailed results show large irregularities, improved arrangements were devised by Meyer, and a differential method used, the ionisation vessel being indicated in fig. 3. The fluctuations were measured with both A and B connected to the electrometer (E_G) and with A alone (E_H). In the first case on the pulse theory there should be no fluctuations (that is, $E_G = 0$), as the two parts of the vessel would be equally affected by the pulse, and

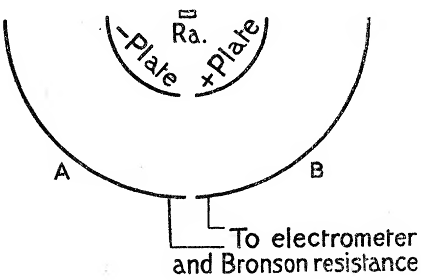

Fig. 3.

A would receive as many negative ions as B receives positive. On the corpuscular theory $E_G/E_H = \sqrt{2} = 1{\cdot}41$; actually the average value of E_G was 1/1000 of a volt, and $E_G/E_H = 1{\cdot}5$. But we think this result is open to objection for practical reasons mentioned later.

Finally, experiments were made to justify the assumption that the number of ions (k or K) formed by a single γ-ray is constant, for otherwise the fluctuations observed might have arisen from variations in k or K. Two experiments were made, the first with the ionisation vessel lined with aluminium and filled with carbon dioxide, and the second with the vessel lined with brass and filled with air, thereby altering the intensity and nature of the secondary rays from the walls and the number of ions formed per γ-pulse or corpuscle. According to Meyer the ratio of the fluctuations in the two experiments would be equal to the ratio of the saturation currents, if k is not subject to fluctuations, for then

$$E_1/E_2 = k_1 e\sqrt{z}/(k_2 e\sqrt{z}) = k_1/k_2 = i_1/i_2,$$

where k_1 and k_2 are the number of pairs of ions per γ-ray in the respective experiments. On this theory, then, $E_1 i_2/E_2 i_1 = 1$, and the observed value of $E_1 i_2/E_2 i_1$ in six experiments was 1·04, 0·93, 1·15, 1·02, 0·90, 0·99, mean 1·00; this warranted the assumption that the number of ions generated by a γ-ray in the vessel used was constant. In other words, it is concluded that, while a number of radioactive effects are subject to variations from the mean, the number of ions formed by a γ-ray is subject to no observable variation. It is interesting to note that von Schweidler came to precisely the opposite conclusion in a theoretical paper (see below) published after Meyer's, viz., that the fluctuation in the number of ions formed per γ-ray would exceed the fluctuation in the number of γ-rays in any ordinarily sized vessel, for many γ-rays would not ionise at all.

Several criticisms of Dr. Meyer's refined experiments would occur to anyone who has used a Bronson resistance and a quadrant electrometer, the instruments which he used to measure the fluctuations. The first is that no evidence is given to show how far spurious fluctuations produced by the Bronson resistance itself* by variations in the 1000 to 2000 volt battery used and mechanical tremors were eliminated. Many of the ions in the experiment of fig. 3 never reach either of the electrodes A or B, so it is not surprising that the largest fluctuation observed in that experiment was very small, being only 1/1000 volt. Further, the results of it are of no significance if this

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* Meyer and Regener, 'Verh. Deut. Phys. Ges.,' January 15, 1908. [This paper was sent to the Royal Society from New Zealand long before the authors could have become acquainted with the recent discussion of this subject.]

1/1000 volt was not quantitatively measured by the quadrant electrometer; no details are given of how such an unusual degree of refinement was obtained.

Dr. von Schweidler, in his second paper,[*] applied the theories of discontinuous phenomena developed by Mr. N. R. Campbell[†] to the experimental conditions indicated by fig. 2. He concluded that, if the γ-rays ionised indirectly,[‡] then:—

I. For *corpuscular* radiation—

$$z_1 = z\omega/4\pi, \qquad k_1(m_1) = k(m),$$
$$\overline{\Delta^2} = \bar{z}\,\omega/4\pi\,.\,\bar{m}\bar{n}^2(\bar{m}+1) = \bar{Q}\bar{n}(\bar{m}+1).$$

II. For *pulse* radiation—

$$z_2 = z, \qquad k_2(m_2) = \omega/4\pi\,.\,k(m),$$
$$\overline{\Delta^2} = \bar{z}\bar{n}^2\{(\omega/4\pi\,.\,\bar{m})^2 + \omega/4\pi\,.\,\bar{m}\} = \bar{Q}\bar{n}\{\omega/4\pi\,.\,\bar{m}+1\},$$

where $\bar{z}$ is the mean number of rays emitted by the source in all directions in a given time,
z is the actual number in a single experiment,
ω is the solid angle of the rays entering the ionisation chamber,
$\overline{\Delta^2}$ is the mean square of the fluctuation in the number of ions in the given time,
k is the number of pairs of ions generated per γ-ray,
m is the number of secondary rays generated in C (fig. 2) by one primary ray,
n is the number of pairs of ions generated by each secondary ray, thus $k = mn$,
$Q = zk$ is the number of ions of one sign liberated in the given time.

On Bragg's view of the process of ionisation by γ-rays $\bar{n}$ would be large compared to 1, and $\bar{m}$ small compared to 1. In that case the fluctuation on both the corpuscular and pulse theories is

$$\overline{\Delta^2} = \bar{Q}\bar{n}, \text{ approx.},$$

and no distinction between the two theories seems to be obtainable by such experiments as Meyer's. If von Schweidler's reasoning and Meyer's experiments are sound, then γ-rays do not ionise as Bragg supposes. Von Schweidler calculates that not 1 per cent. of the γ-rays passing 20 cm. of air would have any effect in it; and, consequently, the fluctuation in the number of γ-rays accidentally effective would exceed the fluctuations in the number entering the vessel.

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[*] Von Schweidler, 'Phys. Zeit.,' July, 1910, vol. 11, p. 614.

[†] N. R. Campbell, *loc. cit.*

[‡] The theory of direct ionisation is also given.

Experimental Methods.

The experiments we have carried out on this question consist essentially in observing the fluctuations, during short periods of time, in the balance of two ionisation cans containing air exposed to the γ-rays from radium. The general arrangements will be seen from figs. 1, 4, 5 and 6.

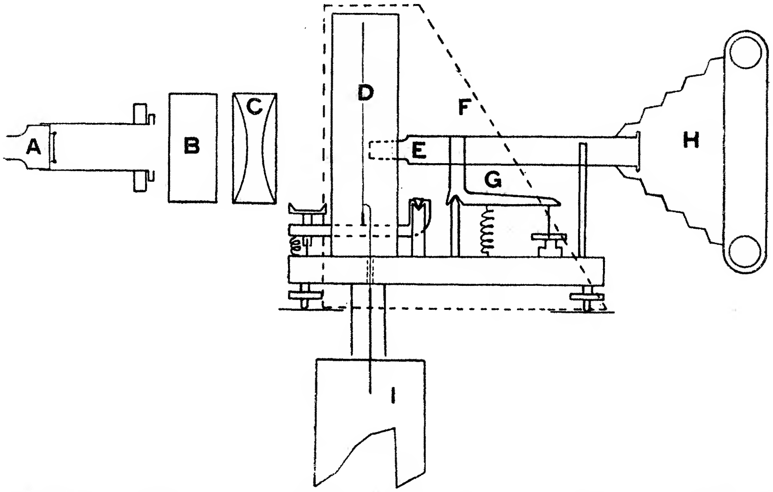

FIG. 4.—A, Nernst lamp; B, cell to absorb heat rays; C, condenser; D, quartz fibre of electrometer; E, microscope; F, lead shield; G, focussing mechanism for microscope; H, photographic camera; I, ionisation can.

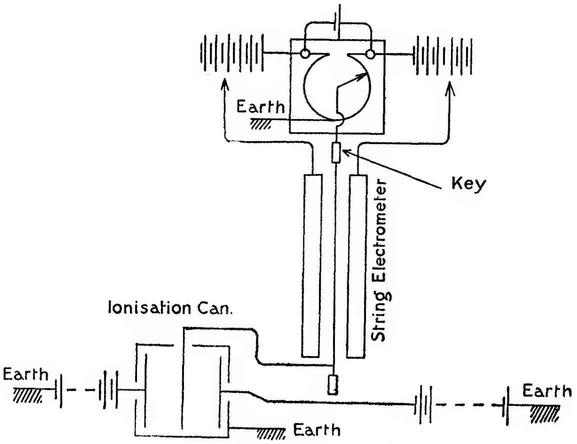

FIG. 5.

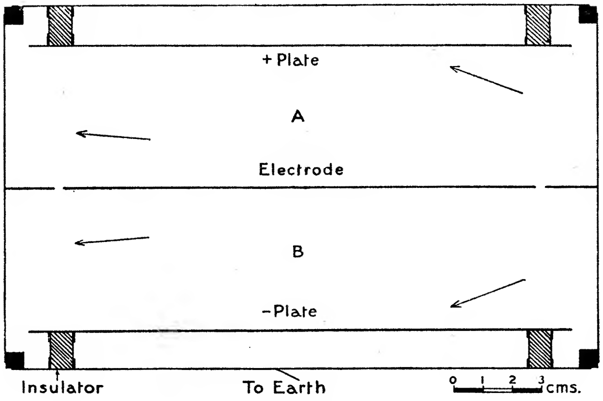

Fig. 6.

Fig. 1 shows the position of the radium with respect to the compartments of the ionisation can; fig. 4 the string electrometer, connected to the electrode of the double compartment ionisation vessel, and the camera for photographically recording the movement of the electrometer fibre; fig. 5 represents the electrical connections of the ionisation vessel and string electrometer; fig. 6 the details of the vessel. In the first experiments two exactly similar cylindrical cans were used, but subsequently these were abandoned for a single box-shaped vessel (figs. 1 and 6) divided into two compartments, A and B, by the electrode, the positive ions from A being collected by one side of the electrode and the negative ions from B by the other side; the excess of positive or negative electricity deflected the electrometer. The compartments A and B were made alike, and so the amount of ionisation in A due to the γ-rays was approximately equal to that in B, when the source of the γ-rays was in the plane of the electrode. A more exact balance could be readily obtained by slightly screening A or B, and so the electrometer fibre could be kept somewhere on the scale of an observing microscope, though its position was always fluctuating to a greater or less degree depending on the sensitiveness of the electrometer and other conditions.

The String Electrometer.—The string electrometer used in these experiments was designed by Mr. Horace Darwin and one of us.* In a previous paper† its characteristics have been described; the present instrument is the outcome of the experiments there described.

The general principle of the electrometer is very simple, a silvered quartz fibre taking the place of the gold leaf of the ordinary electroscope the variations from the usual forms of the latter instrument are that the fibre is fixed at both ends, is placed in a uniform field, and that the middle of it is observed with a high power microscope.

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* The electrometer was exhibited at the Royal Society Soirée in 1909.

† Laby, 'Proc. Camb. Phil. Soc.,' 1909, vol. 15, p. 106.

The string electrometer under notice has been found when once properly set up (which requires a good deal of care)* to be a reliable instrument which needs no attention and for which the sensitiveness is easily adjustable over a wide range. The fibre will follow rapid potential changes and the movements can be recorded photographically.

The electrometer is shown in fig. 7. The silvered quartz fibre of 15 cm. length is supported at one end by B, which is fixed when once the instrument is in adjustment, at the other end by a support on the lever E. These supports are such that the electrical insulation of the fibre is fused quartz.

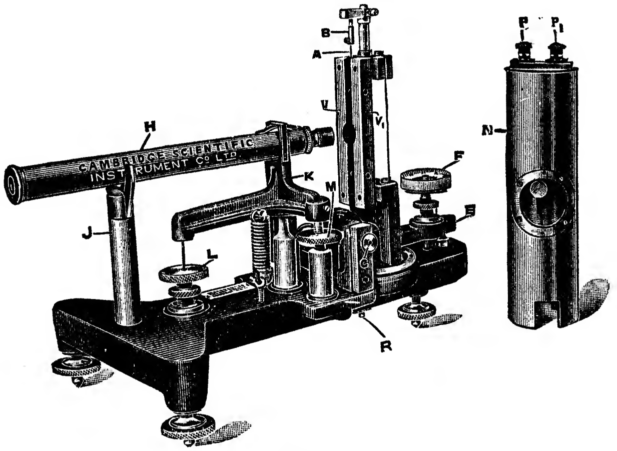

Fig. 7.

The distance between the supports and consequently the fibre tension is maintained by the invar plates V, V′, and so is subject to only small temperature variations. To obtain a fine and regular adjustment of the tension, one end of the lever E has knife-edges resting in geometrical V's, the other end is supported by the micrometer screw F carrying a graduated head. The fibre may be moved laterally by means of the screw G and its counterpart on the other side of the instrument, which slide the knife-edge of the lever E in its own direction. The quartz thread is stretched vertically between the plates V, V′, which are 1 cm. apart and are insulated. To establish the electric field which deflects the fibre these plates are put to a potential of —V and +V, when the fibre is at zero potential.

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* The precautions required in setting up the string electrometer are similar to those required with the Wilson tilted electroscope; it is *essential* to shield the fibre from all air currents, for it is very sensitive to their action.

The motion of the middle of the fibre is observed with the microscope H, using a Zeiss C objective and a No. 3 micrometer eyepiece, a combination giving a visual magnification of 360 diameters. A higher magnification than this is usually less convenient. It will be clear from the figure how the microscope is supported, how the screw L focuses it, and the screw M moves it sideways. This focusing arrangement compares favourably with good microscope movements. It will be seen from the figure of the instrument that all necessary adjustments of the fibre and microscope can be readily made.

The fibre was illuminated by the light from a Nernst lamp (see fig. 4). The heat rays were removed by the cell B, which contained a saturated ferrous ammonium sulphate solution; the remaining rays passed through a condenser and came to a focus on the fibre, which, illuminated in this way, appeared black on a bright ground. A camera shutter for cutting off the light enabled time signals to be recorded on the film.

Sensitiveness.—How the factors (1) distance of the plates apart, (2) their potential difference, (3) the tension of the fibre, affect the sensitiveness of the string electrometer has been considered in the paper previously mentioned. When the electrometer as re-designed was first tested, the potential difference between the plates used was from 40 to 100 volts, but though the high sensitiveness of from 1000 to 1500 eyepiece divisions* per volt could be obtained it was found better to work with a P.D. of from 4 to 12 volts, as the sensitiveness remained steadier and could be conveniently used at over 500 divisions per volt. The sensitiveness can be readily adjusted to a desired value by altering the plate P.D., the tension of the fibre, or the magnification of the microscope; generally an alteration in the P.D. is all that is necessary. For a sensitiveness up to 700 divisions per volt the zero is very steady; beyond this it is subject to slight slow changes. The instrument was designed for recording the fluctuations in voltage such as arise in the investigations of the type initiated by von Schweidler. A few rough tests were made with the electrometer when it was first set up to find how rapidly the fibre would take up a new position when its potential was changed. In these tests the tension on the fibre was increased to alter the sensitiveness, and the P.D. of the plates was kept constant at 100 volts. The following table contains the results obtained :—

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* Magnification 360.

Sensitiveness in eyepiece divisions.	Percentage of full deflection.	Time required.
	per cent.	sec.
130	50	0·3
40	50	0·17
15	66	0·08

Screening.—In the experiments recorded below, the electrometer was screened from the γ-radiation by a heavy lead screen, L-shaped in section and 2·3 cm. in thickness (shown dotted in side view in fig. 4). The effect of the radium on the screened electrometer was deduced, from experiments with additional screens, to be negligible. With the original form of apparatus attempts were made to obtain a definite beam of γ-rays through the two cans by using for each a protecting lead cylinder, 4·5 cm. thick, with a central hole, also by inserting the radium in a lead cylinder, 9 cm. in diameter, with a narrow lateral hole. The definition of the beam thus obtained was not, however, sufficiently good to justify the method.

The Ionisation Vessel.—This vessel was designed (1) to make the whole apparatus as sensitive as possible to fluctuations in the ionisation; (2) to give a uniform electric field of such intensity, using the battery power available, that the ionisation current would be saturated. The second of these conditions implies a parallel plate condenser for the ionisation vessel.

The following considerations are of importance in the design of the ionisation vessel:—Let C be the capacity of the electrode, c that of the electrometer, insulators, and connections, n_1v_1 and n_2v_2 the number of pairs of ions formed during unit time in the effective volumes v_1 and v_2 of air on the opposite sides of the electrode, E the rate of rise of the potential of the electrode and fibre due to the excess of ions generated on one side. If A is the area of the electrode, and d its distance from the plates, then $v_1 = v_2 = v = \mathrm{A}d$.

The rate of deflection of the fibre is

$$\mathrm{D} = \lambda\mathrm{E} = \lambda ev(n_1 - n_2)/(\mathrm{C}+c) = \lambda'\left(\frac{\mathrm{C}}{v}+\frac{c}{v}\right)^{-1} = \lambda'\left(\frac{1}{4\pi d^2}+\frac{c}{v}\right)^{-1},$$

where λ' is independent of the dimensions of the can.

For D to be large, d and v/c or $\mathrm{A}d/c$ must be large, *i.e.* the capacity of the connections and electrometer should be small, and the distance between the plates large. The first vessels made were cylindrical with two electrodes, each parallel to the plane ends; for each can $v = 56$ c.c., $c = 1·1$ cm. E.S.U., $d = 2$ cm.; for the whole system $\mathrm{C} = 33$ cm. E.S.U., or 15 times as much as the electrodes. This large capacity, which was mostly in the four guard-ring insulators and connections, was surprisingly large and made the apparatus insensitive. The distance between the plates had been made small, in order that when using methyl bromide or methyl iodide in the vessels, it would be possible with the available voltage to saturate the ionisation currents for the intensities used. It was found, however, that the ionisation in these vapours was so little greater than that in air as to make their use of no advantage. For example, saturating the air with methyl iodide increased the ionisation about 1·7 times. It was decided to re-design the ionisation vessel, so as to increase the distance between the electrode and the plates, and to use only one insulator so as to make the capacity of this portion a minimum. The increase in d was possible, as Mr. Lattey* and Prof. Townsend find that the very perfect drying of air increases the mobility of ions, from which it would follow that a given ionisation in air dried by phosphorus pentoxide could be saturated with a smaller field than the same ionisation in moist air. As re-designed, the vessel is as shown in fig. 6. Its dimensions are: Plate distance 4·85 cm., capacity of electrode (C) 6·6 cm., effective volume (v) 1950 c.c., and v/c 295 c.c. per centimetre of condenser capacity compared with 50 for the first vessel. On the above theory the fluctuations in the deflection of the fibre with the radium at a given distance should be greater in the case of the second apparatus than in that of the first; this was verified in the experimental work, the increase being quite distinct.

The Batteries.—Since the object of these experiments was to detect the presence or absence of fluctuations under particular circumstances, very steady sources of potential were needed. The steadiness of the voltage of the small accumulators used (supplied by W. G. Pye, Cambridge) was therefore tested, 60 cells at a time being connected to a Kelvin electrostatic voltmeter, which was read with a microscope. The final observations were made with the voltmeter floating in a vessel of mercury, supported on a brick pillar to eliminate vibrations. The changes in the voltage of the cells were found to be not more than 0·01 volt per 120 volts, *i.e.* 0·01 per cent., the time of observation ranging up to 18 minutes. From the character of the curves obtained, it seemed probable that many of the variations found were in reality produced by earth tremors. The steadiness of the fibre (as shown photographically), when connected to the electrode, and so exposed to any induction effects from the potential plates, confirmed the previous experiments. To obtain such constancy, the mercury connections had to be most carefully amalgamated.

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* 'Roy. Soc. Proc.,' July, 1910, A, vol. 84, p. 173.

Observation of Fluctuations.

In taking observations, the main initial adjustments comprised the testing of the insulation of the fibre, and the determination and adjustment of the sensitiveness. In the first experiment, records were taken of the movement of the fibre by plotting readings on the eyepiece scale against a time co-ordinate. The first set of readings was taken with the conditions exactly similar to those under which the radium was to be present later, the connection of the fibre system to earth being broken. Then the radium was brought into position, and the currents in the two compartments of the ionisation vessel adjusted as nearly as possible to equality by partially screening one of the compartments (or, in the original apparatus, one of the cans). Readings were then again taken over a given time. Finally, a third set was taken with the radium removed, and the fibre again free. The absence of fluctuation in the first and last cases eliminated the possibility of spurious effects. The chief causes of these latter were draughts in the electrometer, faulty connections and cells. In some of the final results, all observable effects due to these causes were eliminated.

The original form of apparatus was sufficiently good to show fluctuations in the ionisation due to γ-rays from the radium, but the form now in use shows these more distinctly. Fig. 8 was obtained by one observer plotting the position of the fibre, as called by the other observer, every 5 seconds.

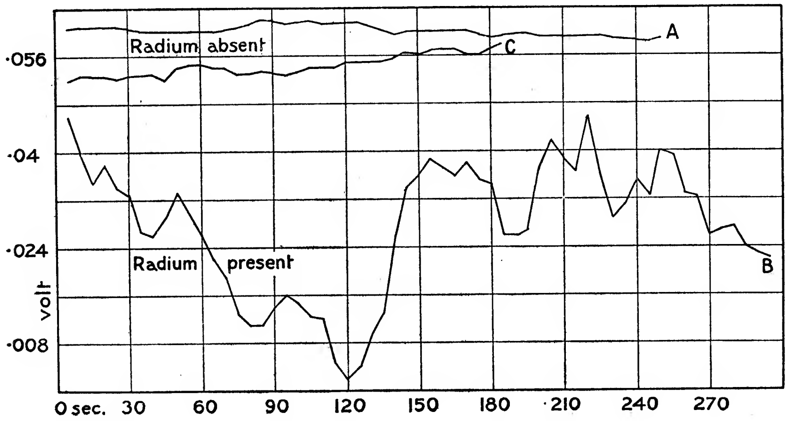

Fig. 8.

In later experiments the movements of the fibre were photographically recorded; a Kodak camera was fitted to the end of the microscope, and an adjustable slit in a brass screen allowed a small portion of the image of the fibre to fall on the film. The latter was wound past the slit by a winding gear, fitted to the ordinary winder on the camera, and driven by a small electric motor. The initial tests and adjustments were made by observing the image on a ground-glass plate. The ionisation currents in the can were balanced at the start, the radium held in an adjustable arm being symmetrically placed (see fig. 1) with respect to the two compartments. The radium could be removed and inserted again in approximately the same position. Time signals on the sensitive film at each operation were made with the shutter on the Nernst lamp. The process consisted in obtaining a record of the position of the fibre in the following order:—

Fibre earthed.
„ free for some minutes with radium present.
„ earthed.
„ free for some minutes with no radium present.
„ earthed.

The graph A of fig. 8 represents the movement of the fibre during 3 minutes 45 seconds with no radium present, and so shows any spurious fluctuations (produced by draughts, mechanical tremors, variations in the E.M.F. of the batteries in use, and in the natural ionisation) which existed immediately before the graph C was obtained; the graph C represents the disturbances due to the same causes existing immediately after the curve B was taken; and B represents the fluctuations during 5 minutes when the radium was present. There can be little doubt that these graphs show that the ionisation produced by γ-rays in air fluctuates.

In fig. 9 are shown two films (curves I and II) on which the position of the fibre was continuously photographed. In curve II, for which the electrometer was very sensitive, giving 1000 eyepiece divisions per volt, γ-rays from the radium were acting during the time from S to T; the fluctuations are clearly shown. From T to U the radium was absent and the fluctuations disappear, although the fibre drifts a little. Curve I gives a similar record; the greater steadiness of the fibre when the radium was absent is due to the lower sensitiveness used—400 divisions per volt, though this particular film is one of the least favourable in this respect. Here, again, from A to B the radium was present, and from B to C absent, the conditions otherwise, when the fibre was free, being exactly similar. The effect of distance of the source of rays is also qualitatively shown by the two curves—I is taken with the radium 20·4 cm. from the front of the ionisation vessel, II with the radium only 5·8 cm. away. The extent of the fluctuations, when both are reduced to the same scale, is much diminished with increased distance—a result to be expected from the decrease in the intensity of ionisation.

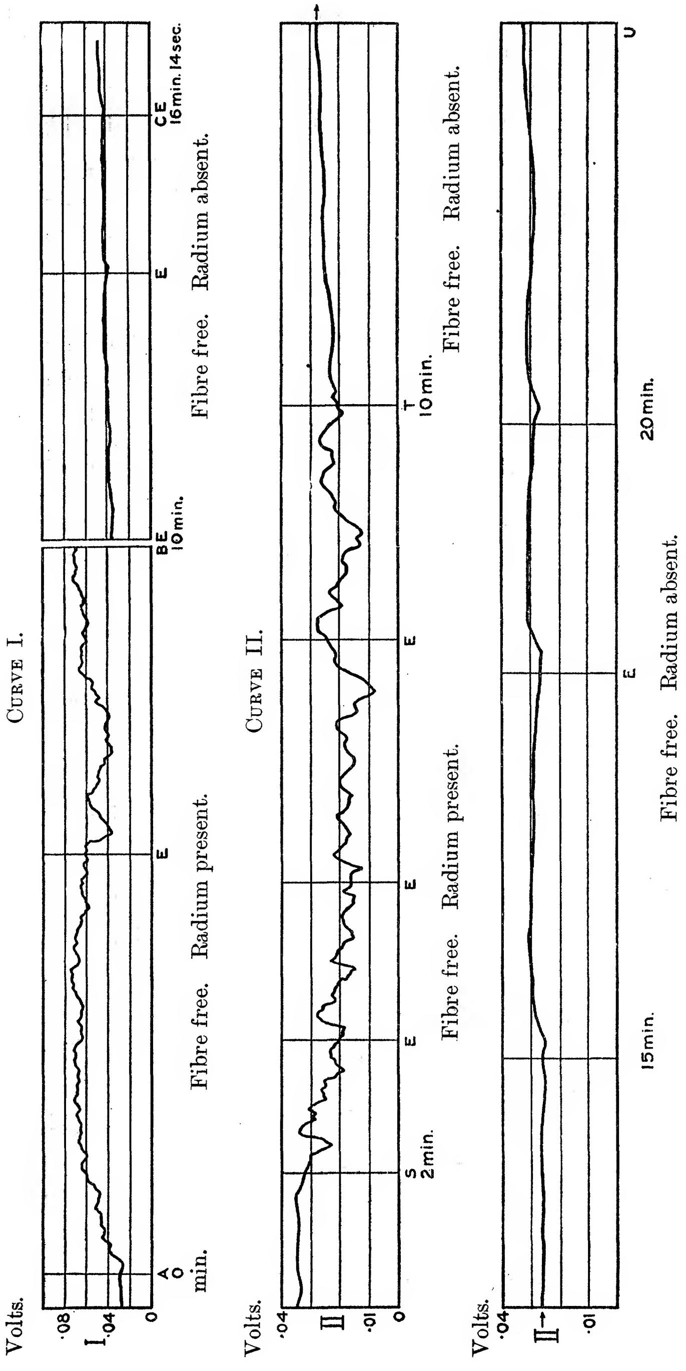

Fig. 9.—Curve I, radium at 20·4 cm. distance; Curve II, radium at 5·8 cm. distance. E = earthed.

The break in curve I at B is due to the fact that the shutter on the Nernst lamp was inadvertently left closed after the signal immediately preceding the earthing of the fibre and removal of the radium.

We think that these records, which are only two of many similar, fully demonstrate the existence of fluctuations in the ionisation produced by γ-rays. By using a string electrometer, which is capable of following more rapidly the changes in voltage of the electrode than a quadrant electrometer, the time necessary to complete an experiment has been reduced; further, we have avoided the use of a Bronson resistance, and any possibility of the introduction of variations by it.

As we have already seen, the fluctuations may be due to the action of two factors—(1) a relative fluctuation in the number of γ-rays entering the two compartments of the ionisation vessels used, and (2) a fluctuation in the number of ions generated in the vessel per γ-ray. It will be necessary to make further experiments to determine the part which these two factors play. If Prof. Bragg's view of the process of ionisation by γ-rays is correct, then the fluctuations we have observed would be almost entirely due to the second factor, and they would not be a proof of the projected entity (corpuscular) theory of γ-rays.

If, on the other hand, Meyer's results with CO_2 and air are correct, then the number of ions generated by a γ-ray is constant, and our results are evidence of the projected entity (corpuscular) nature of γ-rays. We believe that with the apparatus we are using, *i.e.* the double compartment ionisation vessel and the photographically recording string electrometer, it will be possible to obtain a solution of these questions.

These experiments were begun in the Cavendish Laboratory, Cambridge, continued in the Physical Laboratory of the University of Sydney, and completed in Wellington. To Sir J. J. Thomson and Prof. Pollock we are indebted for encouragement and help. The Royal Society rendered the completion of the experiments possible by the loan of the 5 mgrm. radium bromide we have used.

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